

INK-12: Teaching and Learning with Interactive Ink Inscriptions in K-12 Annual Report, Year 1, July 2011

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1. Introduction

The INK-12 project, a full-scale follow-on to a two-year exploratory project, is investigating how the combination of two technological innovations—*pen-based input* and *wireless communication*—can support classroom practices that teach two skills critical to mastering STEM disciplines: 1) *creation and manipulation of representations for mathematical and scientific objects*, and 2) *communication of those representations and associated feedback*. We are investigating how technology that facilitates these capabilities, via a set of networked tablet computers, can support teaching and learning key mathematical and scientific concepts in upper elementary school. *Pen-based interaction* enables creation of inscriptions—handwritten sketches, graphs, notes, etc., which are critical in STEM fields, where content is often most easily expressed as a mixture of text and drawings. *Wireless networking* enables facile communication of inscriptions, and other representations, among teachers and students, and supports formative assessment and classroom discussions directly based on student work.

During our first year, we developed new prototype software and conducted four multi-day trials in fourth and fifth grade classrooms using the two NSF-supported curricula in our proposal: *Investigations in Number, Data, and Space*, and the *Inquiry Project* curriculum. These curricula are committed to students' making meaning of math or science—taking an inquiry approach to each subject and learning how to produce, present, and evaluate evidence. Pedagogical strategies from these curricula that are particularly relevant to the INK-12 project include: students creating mathematical and scientific representations, sharing representations and other work, talking about different approaches to problems, and revising their work in response to feedback.

Observations from our first year activities suggest that our new INK-12 technology, along with the appropriately developed *Investigations* and *Inquiry Project* curricula, will provide instructional possibilities that would not be possible with traditional paper and pencil. Observations also suggest that the INK-12 technology will continue to increase classroom interaction—among students, student and teacher, and whole classes—and may ultimately improve student learning, especially among lower performing students. We believe that this technology has the potential to increase accessibility to science and math topics for a range of students who currently are not performing as well as they could be.

In the sections that follow, we describe the INK-12 interaction model and our research questions, detail our technology development, and describe our classroom trials and findings. Excerpts from the evaluator's report, submitted separately, are included in the last section.

2. INK-12 Interaction Model

The basic classroom setup remains the same as in the exploratory project: In a classroom, the teacher and each student have a tablet computer, and a tablet computer is connected to a projector, creating a public display with which student and teacher machines communicate. Using the tablet computer's pen, each student writes on his or her tablet screen, e.g., answers to problems, then wirelessly submits his or her "digital ink" inscription to the teacher. The teacher can view all student submissions and lead a class discussion by choosing several submissions to annotate and display anonymously via the projector. The exploratory INK-12 project thus supported a *create* and *share* model of interaction. The current INK-12 project extends this model to include an intermediate *interpret* step, designed to aid teachers with what we observed to be a very difficult task—sorting and choosing pedagogically interesting student work for

discussion. Our current *create*, *interpret*, and *share* model of interaction is shown in Figure 1 and described below.

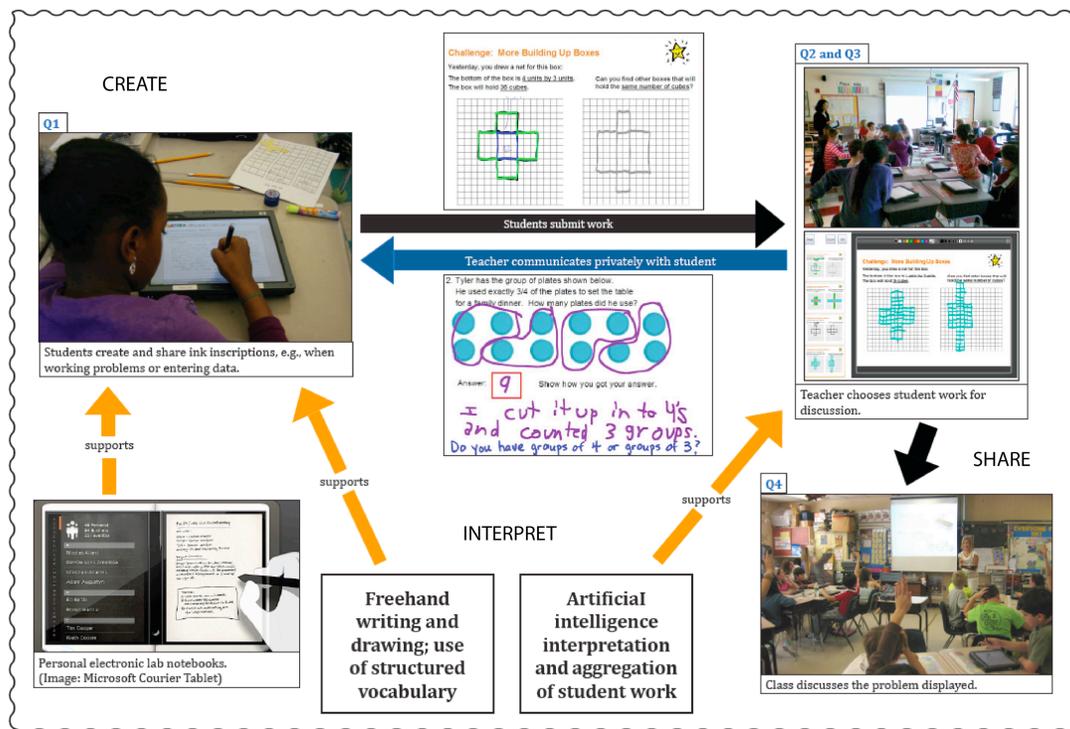


Figure 1. INK-12 model of classroom interaction

Create. Students create inscriptions freehand, as in the example in Figure 2a, and also with the aid of what we broadly call *palettes*—sets of graphical icons that can be used as parts of inscriptions. One kind of palette will contain pre-programmed icons such as geometric shapes, grids, or chemical elements. Another kind of palette will contain icons that teachers and/or students design and define in class so that they are using common representational tools. Such icons are used as “stamps” to create a drawing containing multiple identical images. An example is shown in Figure 2b. The graphical icons create a *structured vocabulary* that can aid interpretation, both by human and by machine.

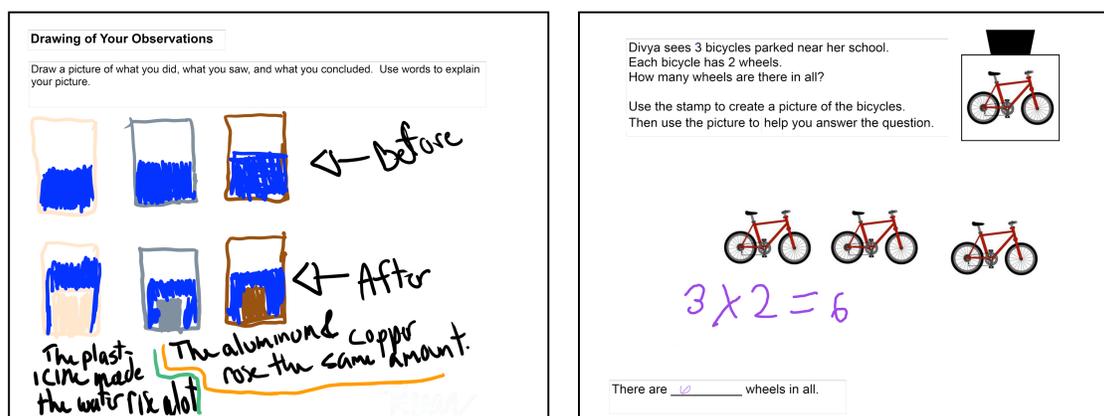


Figure 2. a. Freehand drawing describing a displacement experiment

b. Drawing made using a stamp to solve and explain a multiplication problem

Interpret. To support teachers in viewing, sorting, and choosing student work, we are developing software that uses artificial intelligence (AI) techniques to interpret, aggregate into similarity classes, and assess student work when possible. In some cases it is possible to use handwriting recognizers to interpret student work. Structured vocabularies, e.g., such as the bicycle shown in Figure 2b, facilitate the

interpretation process, as the computer will “know” what icon a student has used and what it represents. A computer, for example, will be able to identify pre-defined bicycles (Figure 2b) more easily than freehand cups and materials (Figure 2a).

Share. Teachers want to be able to display multiple examples of student work and annotate the examples as a way to encourage conversations in which students defend their reasoning and listen critically to others' reasoning. We are developing a variety of formats in which to display multiple examples of student work and tools for writing on the display either before or during class discussion.

With this create, interpret, and share model of interaction, our INK-12 research questions are the following:

1. How do inscriptions created using pen-based technology differ from those created using pen and paper?
2. How do students' inscriptions differ when using palettes—and the resulting structured vocabulary—vs not using them?
3. What effect does the process of selecting and sharing student work have on student participation and learning?
4. What tools can help a teacher choose student work for discussion? What kinds of information about student work can artificial intelligence techniques provide automatically to teachers?

This year we began investigating these research questions by designing and implementing prototype software in the fall and deploying it in classrooms in the spring.

3. Technology Development

In the previous exploratory project, we enhanced software called Classroom Learning Partner (CLP), which had been developed by Kimberle Koile's research group. In the current project, we started over and built the first prototype of the new Classroom Learning Partner, with input from three teachers who participated in the previous INK-12 project. The basic classroom setup remains the same, as described in the previous section: In each classroom the teacher and each student have a tablet computer, and a tablet computer is connected to a projector, creating a public display with which student and teacher machines communicate. Students handwrite answers to problems, then wirelessly send their “digital ink” answers to the teacher, who can view, annotate, and select student answers for anonymous display via the projector. The usage metaphor and software infrastructure for the new CLP differ from the previous version of the software, however. Instead of creating slide “decks” for students, with students navigating from one slide to the next throughout a lesson, teachers create “notebooks”, and students work problems on ordered “pages” in the notebooks. This metaphor is one with which teachers and students are familiar, and it easily and intuitively supports such operations as inserting pages, “flipping through” pages, and creating “sections” for different topics. This next year we will investigate the utility of this metaphor in our classroom trials.

The technology is being designed to overcome the limitations most often mentioned by teachers and researchers using our original version: (1) teachers and student not being able to easily access lessons and student work from previous class sessions, (2) teachers being overwhelmed by the student work available to them and finding it difficult to choose pedagogically interesting examples or to identify students who need help, and (3) teachers not being able to create public displays privately before showing them to students.

In this section we describe our design principles, basic functionality of the first prototype, AI techniques being investigated, and software infrastructure.

3.1 Design Principles

Many of our software design principles remained the same as in our exploratory project:

- *Modularity*: Implement abstracted and modularized code, with clearly defined interfaces between sections; makes it easy to change code without unwanted side effects. This principle is especially important with students developing the software.
- *Portability*: Design with multiple platforms in mind, e.g., web server and smaller tablets. This principle will enable us in later years to run our software on different platforms without reimplementation.
- *Extensibility*: Enable easy access to external programs and devices; e.g., models written by others, sensor devices. We want to broaden the scope of our system by being able to make use of work done by others rather than having to implement everything ourselves.
- *Robustness*: Isolate classroom technology so as not to depend on school networking or computers, which often are not reliable. This principle enables us to quickly and seamlessly deploy our system in classrooms without placing a burden on school staff: We take a local server and tablets into a classroom and set up our own peer-to-peer network among the machines.
- *Simplicity*: Limit functionality to necessary features so that the system is easy to use and requires very little training.
- *UI conventions*: Make the UI easily understandable by adopting conventions similar to other software. Always have the same actions produce same the results, and avoid modes that change affects of actions. When modes are necessary, make them obvious and easily entered and exited, and provide contextual help.
- *User-centered design*: Involve the users early and often in the design. In a later version, make the UI customizable by the user.

3.2 Basic Functionality

Our first prototype of new CLP includes interfaces for students, teachers, and authors. Each interface is organized around a top menu bar, a side notebook page previewer, and a main display area.

3.2.1 Student Interface

The student interface is shown below in Figure 3. The students load and save notebooks, draw or write on notebook pages using multiple pen sizes and ink colors, and erase. They do not use a keyboard. They submit their current notebook page to the teacher by tapping on the “Send to Teacher” icon.

The current prototype supports a single page view in landscape mode as shown in Figure 3. This next year we will investigate the use of single page views in portrait mode and double page views in landscape. The double page view will be useful, as it often is with paper notebooks, for displaying multiple simultaneous representations of math and science problems, e.g., a data table on one page and a graph grid on the opposing page.

The current prototype includes three new features for students: *stamps*, *external program screenshots*, and *webcam* photographs.

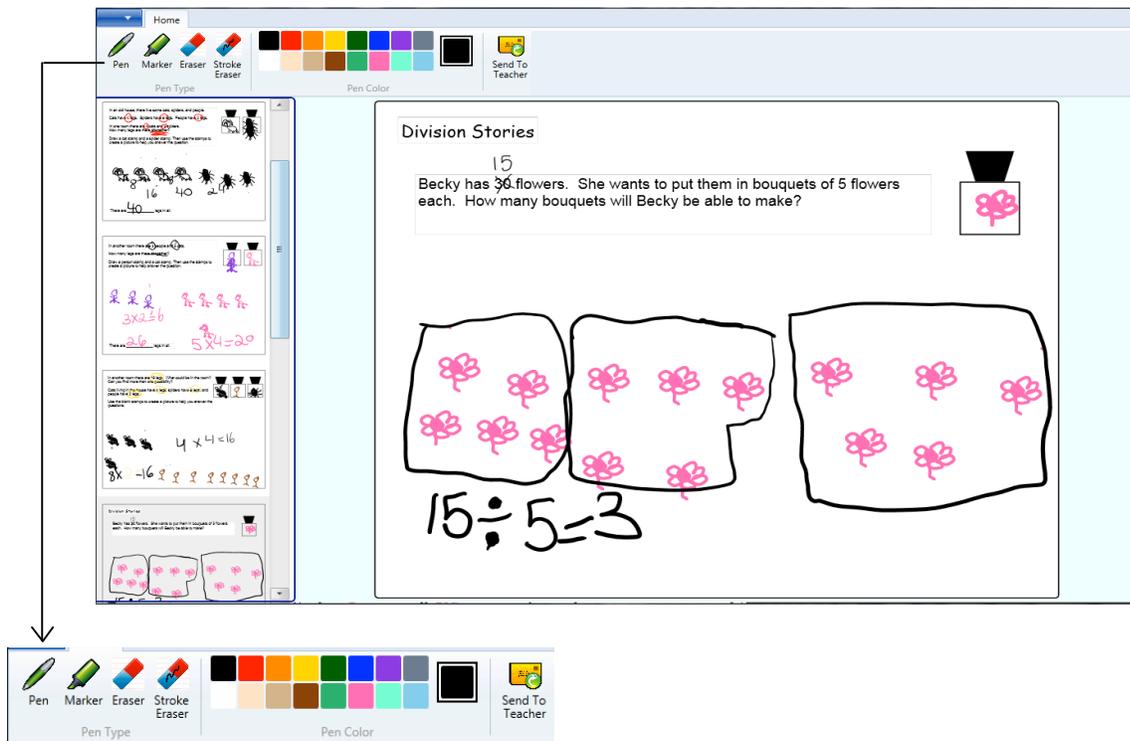


Figure 3. CLP student interface: top command bar for drawing, erasing, sending current notebook page (shown in central display area) to the teacher; preview of pages on left¹

Stamps. In addition to drawing and writing on a page, students can use stamps to solve math problems and explain their solutions. Shown above in Figure 3 is an example of a student-created stamp being used to explain the answer to a division problem: The student draws an image within a blank stamp’s boundary, then drags the stamp to create multiple copies of the image. To drag the stamp, a student places the pen tip on the stamp “handle”—the black trapezoidal shape at the top of the stamp—then drags the pen across the screen to the desired location. To let the student know that the stamp has been “grabbed”, the handle of the stamp turns green, as shown in Figure 4. A copy of the stamp icon, now with a green handle, follows the path of the pen. When the student lifts the pen, a copy of the stamp image appears at the pen’s final location. A student using a stamp to solve a math problem is shown in Figure 5.

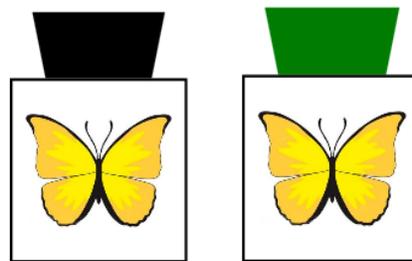


Figure 4. Stamp on left shows a stamp containing predefined image; stamp on right shows stamp appearance when pen is placed over the stamp handle; green handle indicates that stamp has been “grabbed” and can now be moved to create copies of stamp image

¹ Throughout this document, straight arrows in an image indicate more detail, either a close-up view or labeled information; curved arrows show the result of tapping on a section of the UI.



Figure 5. Student writing her answer to a math problem and using a stamp, whose image she drew, to explain her answer

External programs. We extended the system by integrating a “black box” external program with which students could interact. When integrating external programs the challenge is to design a software interface that enables data transfer between the two programs. If the external program is open-source, then we have easy access to the program’s internal data structures and can define an application programmer interface (API) for transferring data to and from the program. When an external program is a “black box”, i.e., not open-source, students must record their interaction with the program by other means. This past year we implemented a screen shot feature for this purpose.

Shown in Figure 6 is a screen shot of a student’s interaction with Crayon Physics (www.crayonphysics.com), a 2D physics puzzle in which drawings are transformed into representations of physical objects that interact with each other as the objects would in the real world. In the example shown in Figure 6, students started Crayon Physics by means of the “Star” icon on the top command bar, and were presented with a picture of three blocks, decreasing in size, with a ramp across the tops. The students were asked to draw shapes above the blocks and document what happened by taking screen shots, annotating one of the screen shots, then inserting the annotated screen shot onto a notebook page. They then sent the notebook page to their teacher.

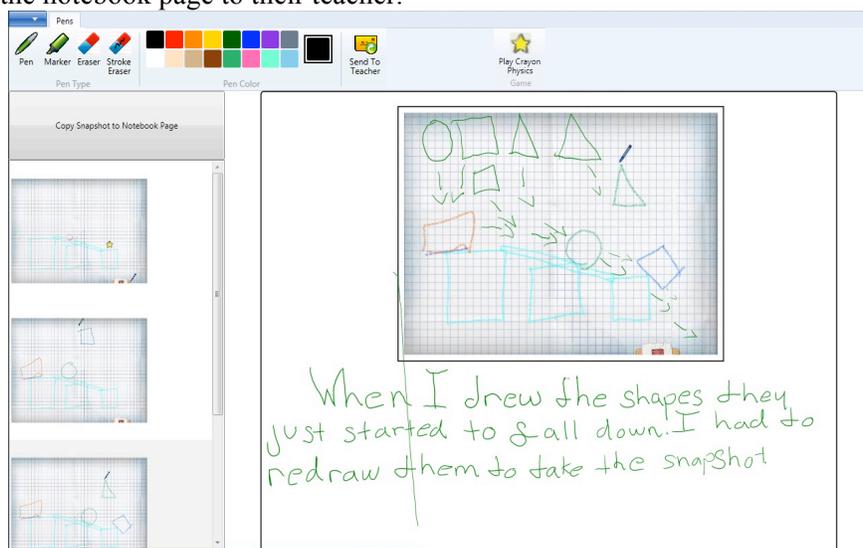


Figure 6. Crayon Physics screen shot chosen from student’s history of screen shots, shown on left; student has annotated the screen shot with arrows and added an explanation below it

Webcams. We provided students with tools to take and save webcam photographs as a way to record their work. Shown in Figure 7 is an example of students using the webcam feature to record steps in a science experiment. The students were asked to build ramps of three different heights and measure the distance a small car traveled past the end of each ramp. They recorded the data in tables in their notebooks. They also took webcam photos of their experimental setup, annotated and inserted one of the photos into their notebooks. Shown in Figure 7 is the window that pops up when a webcam is attached via USB connection to a tablet and a student taps on the “Webcam” icon on the top command bar. When students close the webcam window, their photos appear in a sidebar on the right of their notebook page. (See Figure 8.) They insert a photo from the sidebar onto the page by selecting a photo with either pen or finger, and tapping on the “Put photo on page” button. Students then annotate the photo if desired.

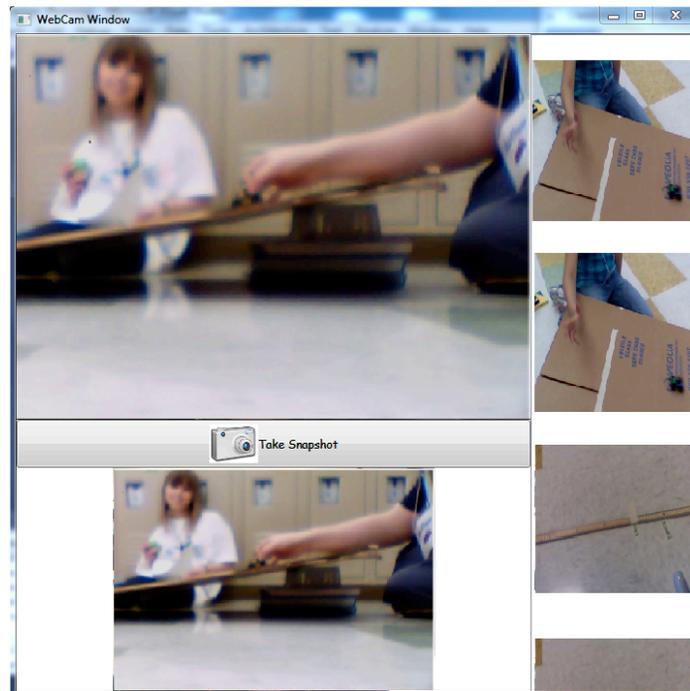


Figure 7. Webcam window: large viewer at top allows students to see camera’s current image; tapping “Take Snapshot” button takes a photo, displaying it at bottom and adding it to right sidebar



Figure 8. Webcam photos appear in the right sidebar and can be inserted onto a page and annotated

3.2.2 Teacher Interface

The teacher interface closely resembles the student interface, with additional functionality provided in each of the three areas of the screen—the filmstrip-like preview areas on the left, the main display area, and the top command bar (See Figures 9 and 10.) The teacher can use these areas to *privately view* student work and to create *public displays* of student work.

Private view of student work. The teacher’s preview areas enable the teacher to monitor class progress; and sort, view, and choose student work. The main display area enables the teacher to view and annotate notebook pages, both hers and those submitted by students, and to tag student work using teacher-supplied tags.

Shown in Figure 9 is an example of the CLP teacher interface. The left preview panel displays notebook pages; tapping on a page displays student submissions for that page in the right preview panel. Then tapping on a student submission in the right panel shows that submission in main display area, along with a menu for attaching tags to student work. (The students’ last names have been obscured for privacy.)

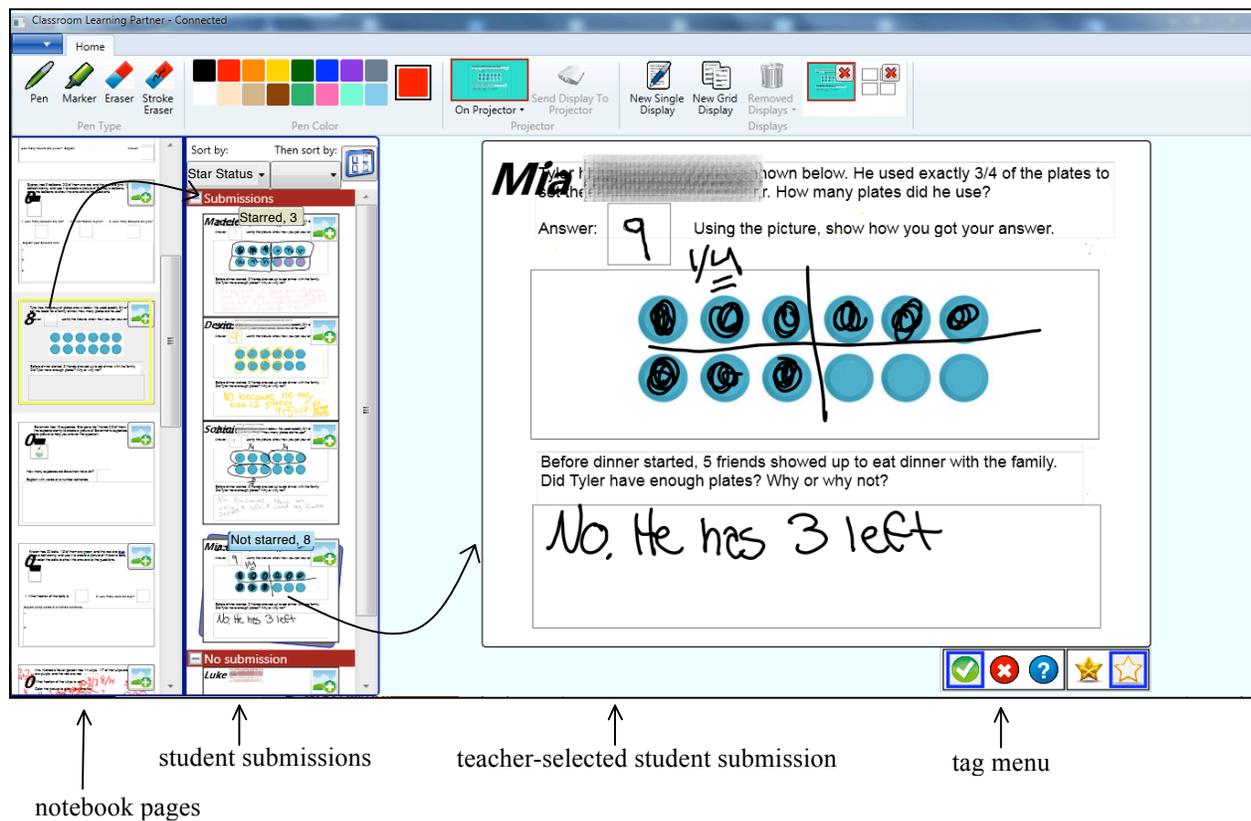


Figure 9. CLP teacher interface: notebook pages in left preview panel; tapping on a page shows student submissions for that page in right preview panel; tapping on a student submission shows that submission in main display area; tag menu shows two categories of tags: correctness and teacher’s “star status” for marking possible candidates for public display

Shown in Figure 10 is a close-up view of the preview area shown on the left side of Figure 9. For each of the current lesson’s notebook pages, shown in the leftmost panel, CLP displays a count of the number of students who have submitted a solution for the page. The teachers use these counts to monitor student progress, e.g., in order to know when to bring the class together for discussion. By tapping on a particular teacher notebook page in the left panel, the teacher can see in the right panel the submissions for that page. She also can see which students have not yet submitted their work. (See bottom of second panel in

Figure 10.) Tapping on a particular student submission, shows that submission in the main display window, as shown in Figure 10. Thus by tapping on previews of various notebook pages, the teacher can navigate through her own and her students' submitted notebook pages in order to monitor progress and choose student work for public display. (See next section for discussion of creating public displays.)

Also shown in Figure 10 is an example of sorting student work. A teacher has marked three student submissions as "Starred" using the tag menu shown in Figure 9. She then sorted the submissions using the "Sort by" button at the top of the submissions panel in order to put those submissions at the top. She now is about to sort those submissions by name, i.e., alphabetically, by tapping on the second sorting button and selecting "Name". As we investigate the use of AI methods for interpreting student work, we also will investigate the possibility of automatic tagging of the work.



Figure 10. Close-up view of CLP teacher interface shown in Figure 9: left preview area displays teacher notebook pages, with counts of number of students who have submitted each page; right preview area displays student submissions; submissions can be sorted by teacher-specified categories, three are shown here

In addition to previewing student work in a filmstrip-like panel, the teacher can view student work in a grid, as shown in Figure 11: Tapping on the grid icon in the upper right corner of the preview panel expands the panel to the full width of the screen. This view enables the teacher to see more student work at the same time, which facilitates comparing and selecting student work.

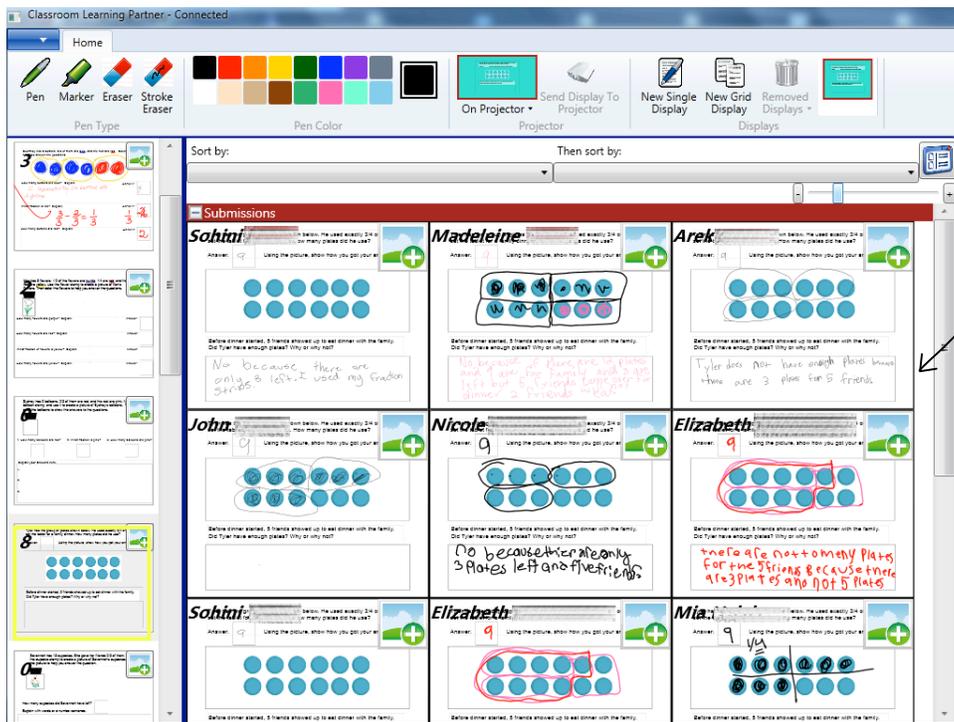


Figure 11. Grid view of student submissions

Public view of student work. We designed, with input from our three teacher-developers, two types of displays for publicly viewing student work: one that shows a single notebook page and one that shows multiple notebook pages. Teachers create the displays—before, during, or after class—using the commands New Single Display and New Grid Display, shown below in Figure 12. Each of these commands turns the main display area into a “canvas” onto which teachers add notebook pages. (See Figure 13.) In the current version of the software, the teachers add the pages by tapping on the “+” sign in the upper right corner of the notebook pages. After adding pages to the canvas, the teacher can either send the newly created public display to the projector, via the Send Display to Projector command, or create another public display to be either sent to the projector or saved along with the first display. Each public display is accessed via an icon on the top command menu bar and can be removed by clicking on the “X” in the icon’s upper right corner. Finally, the teacher easily can be reminded of which public display is being projected by tapping on the “On Projector” icon on the top command bar. This functionality was requested by the teachers, who often found that they had difficulty knowing what was being displayed to the class when they were circulating among students. (See the Classroom Findings section for more details on how teachers used the public displays.)



Figure 12. Top command bar in teacher interface

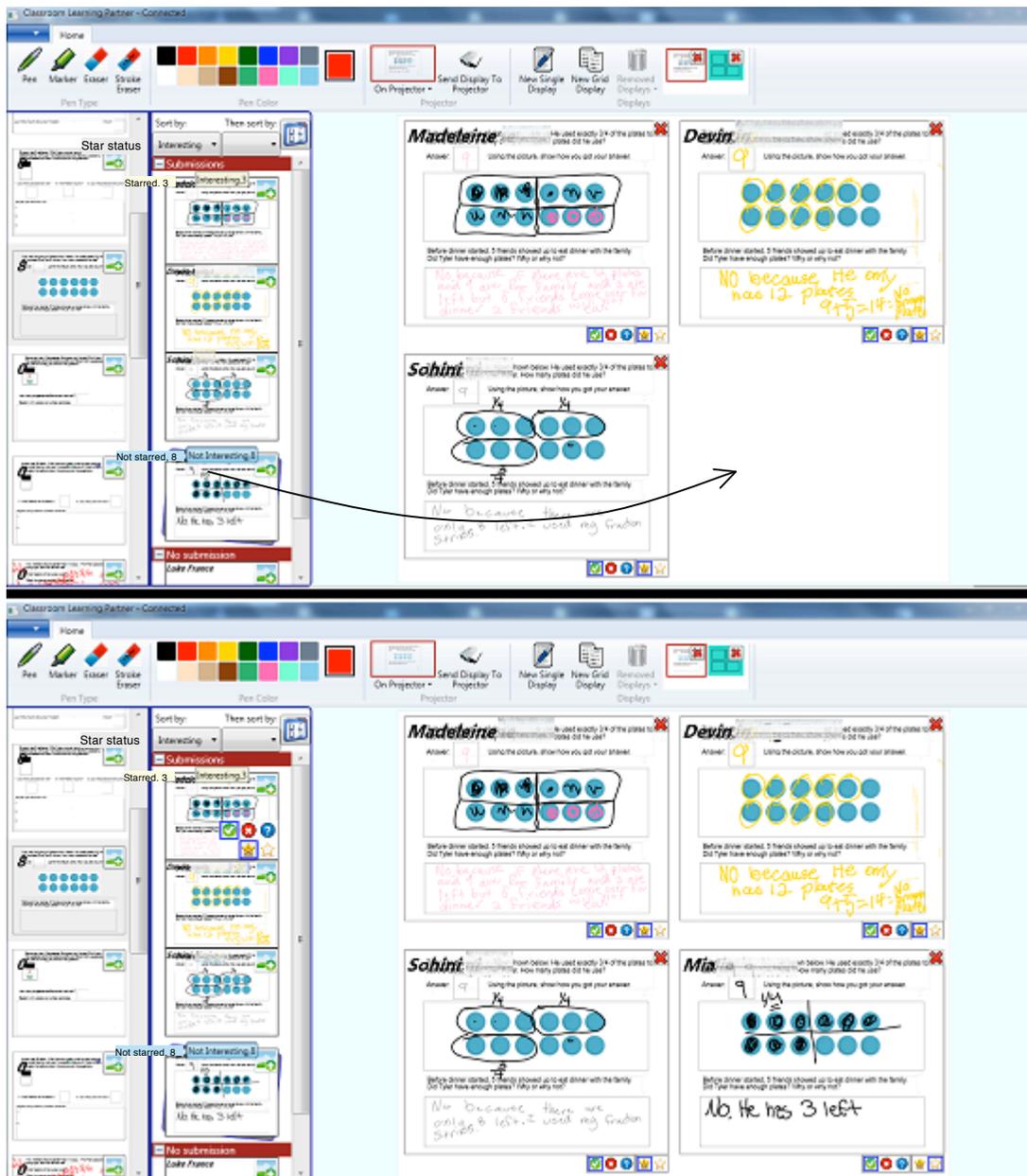


Figure 13. Creating a public display of student work: tapping on “+” associated with a notebook page adds that page to the public display being created in the main display area

3.2.3 Author Interface

Authors, generally researchers or teachers, create a notebook or reload a previously created one, then add pages and write, draw, or erase using the tablet pen, creating lessons for students. They write or draw using multiple thicknesses of ink (pen or marker) and a variety of colors. They also can insert images, stamps (blank or with predefined images), or grids for tables or graphs; or add text using the keyboard. The available authoring commands are shown in Figure 14; we will implement additional functionality as needed. As also shown in Figure 14, previously created pages are visible in the filmstrip-like preview area on the left; the current page being authored is in the main display area. In the example below, the author has inserted text for a multiplication problem and a stamp for students to use in creating a picture that explains their answer to the problem. The salmon-colored background indicates that the authoring commands are available on the command bar.

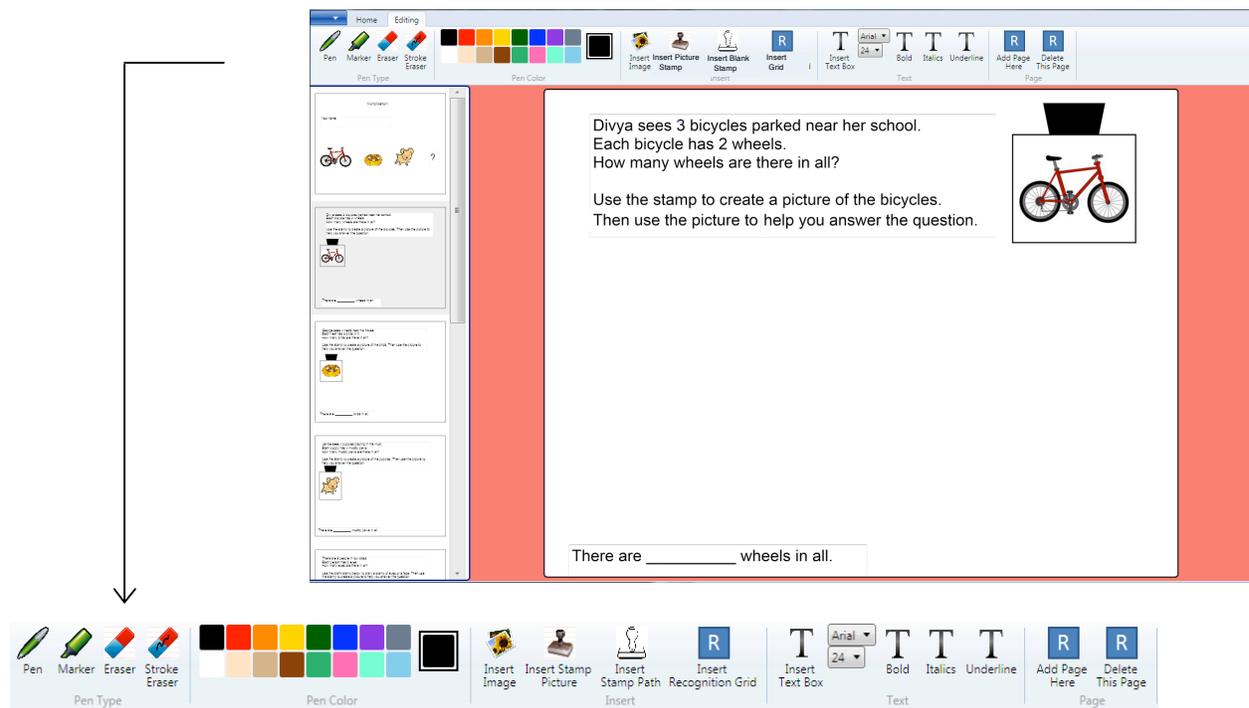


Figure 14. CLP authoring interface: authors create pages, draw, write, or erase on the pages; and/or insert images, stamps, grids, or text

3.3 AI Techniques

We are investigating the idea that software can provide “intelligent” assistance to teachers in viewing, sorting, and choosing student work both during and after class. The key to the assistance that we envision is “ink interpretation”—translating the ink strokes on a screen into a machine-readable format that then can be used to “understand” and reason about the ink. With such interpretation, our software will be able to provide teachers with not just an image of a student’s work, but with information about the meaning of that image. With such information, we hypothesize that a teacher will be able to make faster and better decisions about which pieces of student work to use in classroom discussion and how to structure the discussion. She also can use the information retrospectively in planning subsequent lessons.

This year we investigated the machine interpretation of answers involving text, tables, graphs, number lines, and shaded fractions of shapes. For interpreting text, we used Microsoft’s built-in handwriting recognition software and tested its accuracy with fourth and fifth grader’s handwriting. For interpreting the other answer types, we developed techniques based on using a grid to discretize groups of continuous ink strokes. Below is an example of a problem used to test machine interpretation of ink strokes. The results of our testing the interpretation routines is described in the Findings section.

Use the marker to color in $\frac{1}{2}$ of this shape.



Figure 15. Example of exercise used to test interpretation of ink strokes

3.4 Infrastructure

CLP runs on a set of tablet computers, each of which communicates wirelessly with a local server and with neighboring tablet computers. The local server provides a means for supplying each tablet computer with class materials, e.g., roster and lesson notebooks; and for persistently storing student work. The current version of the server stores student work in a file system. We are designing a database that will run on the local server to save student work during class, then be synched after class with a remote server that will enable teachers, students, and parents to easily access student work via a web-based interface.

The wireless network that facilitates communication between the tablet computers utilizes the Microsoft Windows Communication Foundation (WCF) framework. The subset of WCF that CLP employs uses a peer-to-peer TCP connection and a service called network discovery that enables a machine to dynamically create connections with two to seven of the closest machines on the same subnet—in our case a network created by a wireless router. The number of connections varies to optimize load balance among the machines in the resulting mesh network. The mesh network is ideal for our purposes because it combines the error-correcting assured delivery of a TCP connection with the propagation of a message to every machine in the mesh. When one machine needs to send a message, it sends the message to every machine to which it is directly connected. Those machines, in turn, repeat the message to the machines to which they are connected. This action propagates the message across the entire network and ensures delivery to one or more destinations. One of the benefits of WCF is that it guarantees future interoperability between other platforms: WCF can seamlessly convert messages to a universally readable XML format that can be read by any other computer language. This capability will allow CLP to interact with a multitude of other devices, such as iPads and smart phones—devices that are becoming increasingly prevalent.

4. Classroom Trials

As mentioned earlier, we conducted classroom trials in fourth and fifth grade classrooms using the two NSF-supported curricula in our proposal: *Investigations in Number, Data, and Space*, and the *Inquiry Project* curriculum, both of which were developed at TERC by Andee Rubin and her colleagues.

Prior to the classroom trials, we observed teachers in order to collect baseline data about classroom characteristics such as: how the teacher combined individual work, group work and class discussion; how much students had the opportunity to share their work with the rest of the class; and how much students helped one another, even during individual work time. We intend to analyze that data in order to gauge our technology's effect on these factors.

Prior to the trials, we also tested software features in the three classrooms in which we would conduct the trials. We also met with teachers for two hours prior to the first class in order to familiarize them with the software. (The software is easy to learn to use and extensive training was unnecessary.)

We conducted four multiple-day trials in two different schools in Spring 2011. Each daily session lasted between 90 minutes and several hours. After each classroom trial, we continued to refine the software based on our observations and interviews with students and teachers. The trials were:

1. Northeast Elementary School, Waltham, grade 4 students. One classroom; three-day residency, emphasis on math (fractions) and science (ramps). Class size 15 students.
2. Northeast Elementary School, Waltham, special needs students grades 4 and 5. One classroom; two-day residency, emphasis on math (multiplication and division). Class size 7 students.
3. Baldwin Elementary School, Cambridge, grade 5 students. One classroom; four-day residency, emphasis on math (data and graphs) and science (displacement). Class size 22 students.

- Baldwin Elementary School, Cambridge, grade 4 students. One classroom; four-day residency, emphasis on math (multiplication) and science (displacement). Class size 22 students.

A typical classroom session would begin with a member of the INK-12 team and/or the classroom teacher introducing the activity, the content expected, and what students were to do and what they might expect. Next students would work on their tablets while the teacher or other assistants roamed the classroom, helping students individually. When students felt they had responded or completed the set of questions or tasks, they would submit their work to the teacher, whose own tablet would notify her and save the submission. When the specific activity was completed, (or when the teacher decided it was), the class would look up from their computers and collectively view the presentation screen, upon which selected student work was shown to prompt a discussion. After discussion, students returned to their tablets; sometimes to revise their work, sometimes to work on the next problem in the sequence. Often, the tablet session ended with the teacher commenting and reviewing what the class did that day, and what the gains or problems were.

Below are examples of student work from a fourth grade session on fractions. Also shown throughout this document are examples of additional student math work with fractions (Figures 5, 9), multiplication and division (Figures 2b, 3, 19, 20), data and graphs (Figure 18); and student science work with ramps (Figures 7, 8) and displacement (Figures 2a, 17, 21).

Left Panel: Courtney's Buttons

Courtney has 6 buttons. $\frac{2}{3}$ of them are blue, and the rest are red. Color the buttons to help you answer the questions.

How many buttons are blue? Explain. Answer:
 I separated the six buttons into 3 groups.

What fraction is red? Explain. Answer:
 there are two ways to get $\frac{1}{3}$ or $\frac{2}{6}$. the answer is $\frac{1}{3}$ or $\frac{2}{6}$.

How many buttons are red? Explain. Answer:
 there are two buttons that are red and 4 are blue.

Right Panel: Ken's Flowers

Ken has 8 flowers. $\frac{1}{2}$ of the flowers are purple, $\frac{1}{4}$ are red, and the rest are yellow. Use the flower stamp to create a picture of Ken's flowers. Then color the flowers to help you answer the questions.

How many flowers are purple? Explain. Answer:
 4 because half of eight would be 4.

How many flowers are red? Explain. Answer:
 2 because $\frac{1}{4}$ of eight would be 2 red flowers.

What fraction of flowers is yellow? Explain. Answer:
 if I half of the flowers are purple and $\frac{1}{4}$ of the flowers are red then $\frac{1}{2}$ of the flowers are yellow.

How many flowers are yellow? Explain. Answer:
 2 because $\frac{1}{4}$ of eight would be 2.

Figure 16. Example work on fractions: student colored teacher-created images (left), student created and colored her own images using a stamp (right)

5. Findings

We collected data in the classrooms listed above, from the following sources:

- Classroom video, logged and used to track student's use of and reactions to the tablets
- Transcripts of teacher interviews, carried out by the project evaluator
- Written observations of classroom lessons, both with and without tablets being used; observation forms are included in the Appendix.
- Written field notes on student focus groups
- Student work created on the tablets
- Still photos of the classroom and projected images

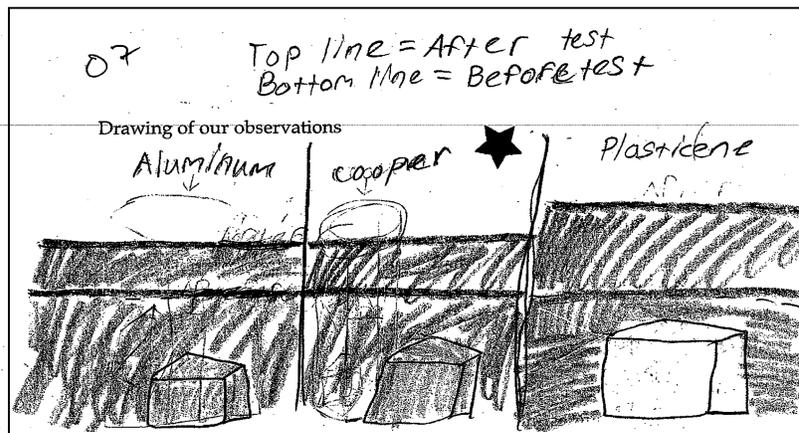
5.1 Classroom Findings

The following findings are organized around the research questions presented in Section 2.

1. How do inscriptions created using pen-based technology differ from those created using pen and paper?

One set of affordances provided by the tablets, compared to paper and pencil, involves the availability of a wider set of drawing options, including multiple colors, different widths of pen, and easy erasing. While the availability of color may not seem a novelty, many students remarked that they rarely had enough colored pencils or crayons to go around, especially at the end of the year, and they often had to share the most popular colors. The two drawings below show how the use of color enhanced students' drawings of the results of an experiment about displacement.

The experiment led students to explore whether an object's volume or weight determined how much water it displaced. They had three objects: two cubes of the same volume but different weights (one copper and one aluminum) and a piece of plasticene of the same weight as the aluminum, but a larger volume. Students weighed each object, then placed each in a cup of water in which they had poured the same amount of water. They recorded the height of the water with the object submerged. Below are two students' drawings of their observations. The top picture was done in pencil on paper; the bottom one was done on a tablet. While the top one is a very good response, the bottom one is enhanced by the use of color and the tablet pen. It's clear that there was water (or some blue liquid) in the cups and the three cubes are represented by three different colors (although the plasticene was not transparent!).



Error!

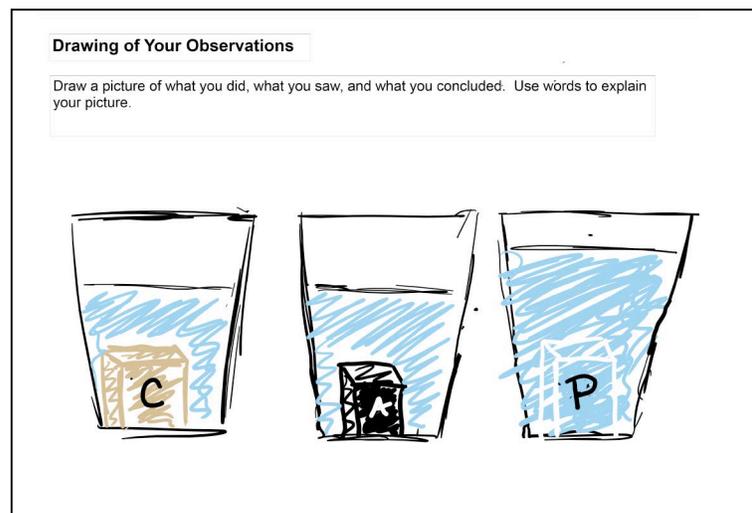


Figure 17. Two students' drawings from a displacement experiment: the top one was done with pencil and paper; the bottom one was done on a tablet

We have also heard from many students that they like being able to erase without leaving a mess. We have informally observed students erasing wrong answers, extra marks, etc., although we haven't yet implemented the ability to replay the entire sequence of students' use of the pen, including erasures. We will be implementing this feature in Year 2, so that we will be able to report more accurately on the ways in which students use the ability to erase.

Our classroom observations provided an example of a problem in which erasing may be part of a solution strategy, i.e., a math problem that can be approached using successive approximations. In the example below, the instructions are to fill in the table so that it illustrates this story: "Tony was 85 centimeters tall on his second birthday. He grew at a steady rate until he was 10 years old. On his tenth birthday, he was 135 centimeters tall." One way to work on this problem is to choose a reasonable increment, then calculate Tony's height at each age sequentially, ideally getting close to 135 cm at age 10. One student took this approach, adding 5 centimeters every year to Tony's height. When she got to 9 years, however, Tony was only 120cm. In order to get to 135 cm, Tony would have to grow 15 cm in one year. She decided that was unrealistic, so she erased all of her numbers and started over, eventually arriving at the solution below, in which Tony grew 5 inches some years, 6 some others and 7 in some others. It's impossible to know how she might have dealt with the same situation had she been using pencil and paper—it's possible she would have just left her numbers as they were and had Tony grow 15 inches in the last year, rather than make a mess erasing everything, even though it was a less satisfying answer to the problem. In Year 2, we will get more insight into inscriptional affordances of tablets by comparing classrooms in which a math topic is taught using the tablets and one in which tablets are not used to teach the same topic.

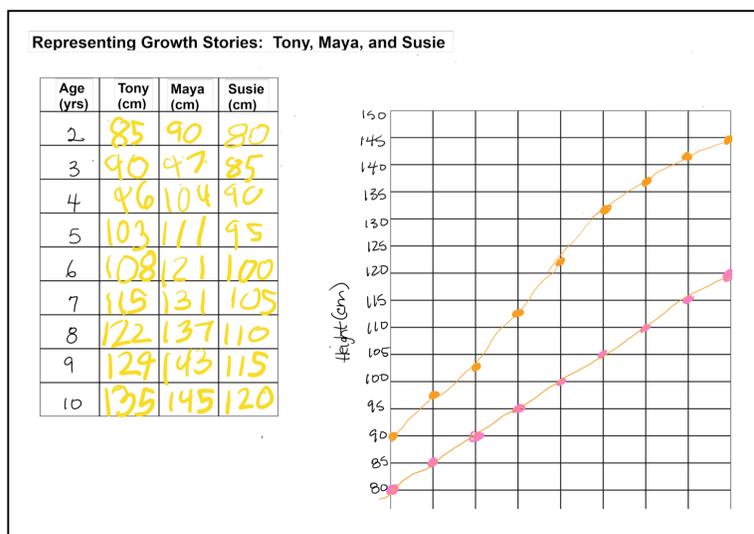


Figure 18. Andrea's final table and graph illustrating Tony's growth story

2. How do students' inscriptions differ when using palette objects—and the resulting structured vocabulary—vs not using them?

In Year 1, we implemented one kind of palette object, i.e., stamps, described above in Section 3. Stamps are different from other palette objects we will implement in Year 2 because they have no parameters; they are reproduced exactly as they appear on the stamp object. In contrast, consider geometric objects: a circle palette object's diameter is a parameter that is only determined when the user chooses, places, and stretches the circle.

The original idea for stamps came from our recognition that there are many kinds of computational problems in which students may find it helpful to draw multiple copies of an image. We used stamps

primarily in the context of multiplicative relationships, as a way to illustrate part/whole relationship. In some cases, we provided a stamp with an image on it, e.g., a nest containing three birds, that illustrated the part/whole (birds/nest) relationship and asked students to use the image to solve and explain multiplication problems. The example below shows a student using a nest stamp we provided to figure out how many birds are in four nests.

George sees 4 nests near his house.
Each nest has 3 birds in it.
How many birds are there in all?

Use the stamp to create a picture of the birds. Then use the picture to help you answer the question.




$3 \times 4 = 12$

There are 12 birds in all.

Figure 19. A multiplication problem being solved using pre-drawn stamps

We also developed blank stamps on which students could draw their own images. The story problem situations were analogous to the “nest has 3 birds” and “bicycle has 2 wheels” multiplication problems shown earlier. The most complicated were a set of “legs” problems, for which students sometimes needed to create more than one stamp. Below is one of the “legs” problems and the solution created by a fourth grade special education student. Note that this student drew both a spider stamp and a cat stamp and used them to figure out that there were 40 legs in all. The special education teacher noted that the stamps appeared to be just the right amount of structural scaffolding for her students; it was clear how the students were to start (draw the stamp) and what they had to do next (create several copies of the stamp). In Year 2, we are carrying out an in-depth investigation of how stamps, and other tools we will create as the need arises, can support fourth and fifth graders who are struggling with multiplicative relationships. We are working with a self-contained classroom of six low-aptitude students.

In an old house, there live some cats, spiders, and people.

Cats have 4 legs. Spiders have 8 legs. People have 2 legs.

In one room there are 4 cats and 3 spiders.
How many legs are there altogether?

Draw a cat stamp and a spider stamp. Then use the stamps to create a picture to answer the question.




$8 \times 3 = 24$



$4 \times 4 = 16$



There are 40 legs in all.

$24 + 16 = 40$

Figure 20. A fourth grade special education student’s answer to one of the “legs” problems.

3. What effect does the practice of focusing class discussion on student work have on student participation and learning?

We haven’t collected enough data yet to answer this question. We have collected preliminary data during non-tablet lessons in which students participated in discussions, noting whether they were called on by the teacher or volunteered, but we don’t have parallel data using the tablets. Our hypothesis is that student participation may be more evenly spread among students if the teacher makes sure to use student work from everyone in the class, especially shy students who might not volunteer on their own. An upcoming version of the software will make it easy for a teacher to keep track of whose work she has shown recently.

4. What tools can help a teacher choose student work for discussion? What kinds of information about student work can artificial intelligence techniques provide automatically to teachers?

We have provided tools to support teachers in organizing, grouping, and choosing student work; the results of that development will be described here. The results of our work on artificial intelligence methods are described below in Section 5.2.

We have developed a sorting structure that allows teachers to sort on two variables at once: “correct/incorrect/unknown” and a teacher-defined tag we currently call “starred.” For now, each of these variables can be set by the teacher by clicking on the appropriate icon appended to the bottom of a piece of student work in the teacher view of student submissions. Eventually, we hope that AI-based techniques will be able to set the value of correct/incorrect/unknown. We also plan to add more teacher-definable tags to allow teachers to use multiple rubrics for student work. Shown below, and described in more detail in Section 3.2, is an example of the teacher view of a grid of four pieces of student work—notice the tag icons in the lower right hand corner of each of the pieces of student work. Once the student work is displayed on the projector, neither the student names nor the sorting tags are visible.

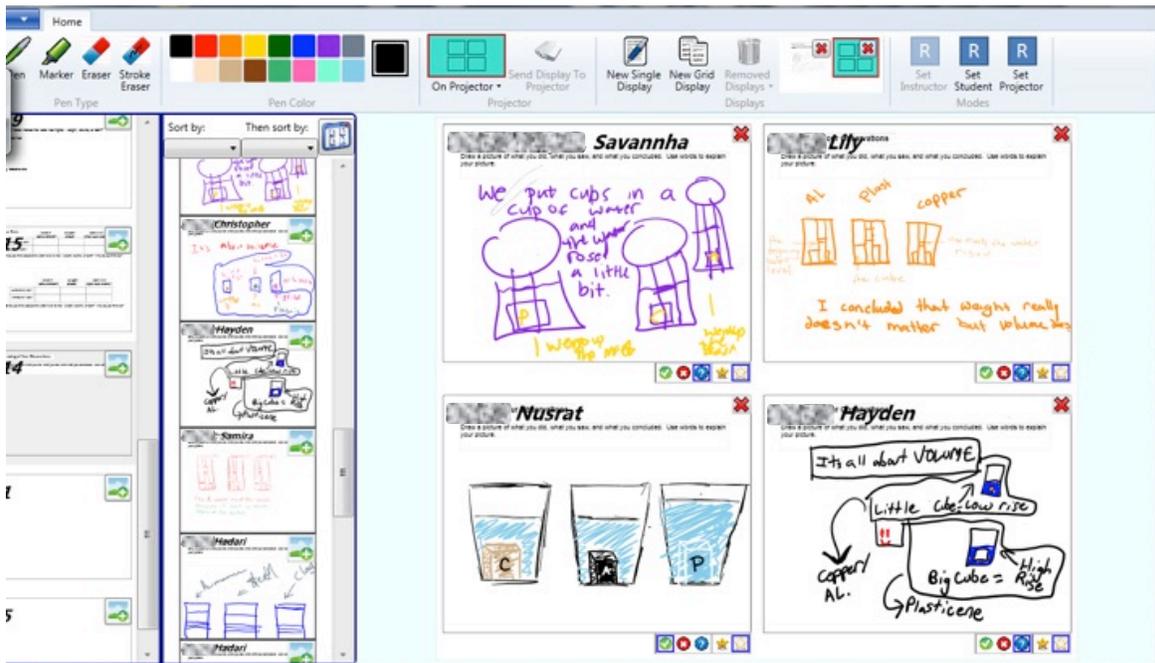


Figure 21. Four pieces of student work selected and arranged to support classroom discussion, with sorting tags visible to the teacher

The teachers easily used this interface to look through student work and create displays to be projected to the class. They had no trouble navigating to student submissions using the two leftmost panels. The tagging and sorting functionality was used several times, mainly to “star” student work teachers wanted to use as examples to show the class at a later time. They did not tag student work as correct or incorrect, feeling that they did not have time during class; they expressed great interest in having the software take on that task. One teacher used the correct/incorrect functions at home after class; she browsed through student work at her convenience. She was thrilled to have all of her students’ work in one compact machine, rather than as large piles of paper. In Year 2, as the teachers grow more facile with the software and classroom practice, we will track teachers’ use and preferences with respect to evaluating student work.

One teacher used the multiple display in a novel way that we had not anticipated: She created a display that showed three notebook pages containing problems that she wanted the students to work. While this display was being projected, students worked the problems, and the teacher privately created new displays containing examples of their work. When the students had completed the work, she then projected and discussed each of the student work displays she had created.

5.2 Technology Findings

We report here our findings related to *stamp design* and use of AI techniques for *intepretation of student responses*.

Stamp Design. The stamp idea afforded us the opportunity to test the tablet computers’ pen vs touch interaction modes: Given a stamp, either blank or containing a predefined image, students could create multiple copies of the stamp image by dragging the stamp icon using a finger or a pen. Given the popularity of touch screen technology such as the iPad, we expected students to prefer using the touch screen on the tablet. What we found was the opposite: Most students preferred the pen—they could more accurately place the stamps by tapping on part of the stamp and dragging to the desired location on the screen; the screen was not obscured by their hands when dragging the stamp; they didn’t have to change their grip on the pen, as they did when using a finger for dragging the stamp and a pen for annotating their resulting drawing; and they experienced increased friction when dragging the stamp over long distances with a finger.

In addition to experimenting with using a finger to interact with the stamps, we tried various methods of interaction with a pen:

Idea 1: Place pen on the stamp. Pros: Most intuitive action; Cons: Doesn’t allow the user to draw/color on the stamped image; pen would only be used to move the stamp.

Idea 2: Place pen on area between stamp and bounding box after hovering over stamp. Pros: Allows user to draw/color on the stamp; Cons: Area between stamp and bounding box can be annoyingly small; too easy to miss the area and accidentally draw on the stamp.

Idea 3: Place pen on stamp handle after hovering over stamp. Pros: Allows user to draw/color on the stamp; clear feedback about when stamp can be moved; Cons: Requires decision over placement of handle; not immediately obvious to users that a handle will appear on hover.

Idea 3 turned out to be the best design, and different handle designs were tried, as shown in Figure 22.

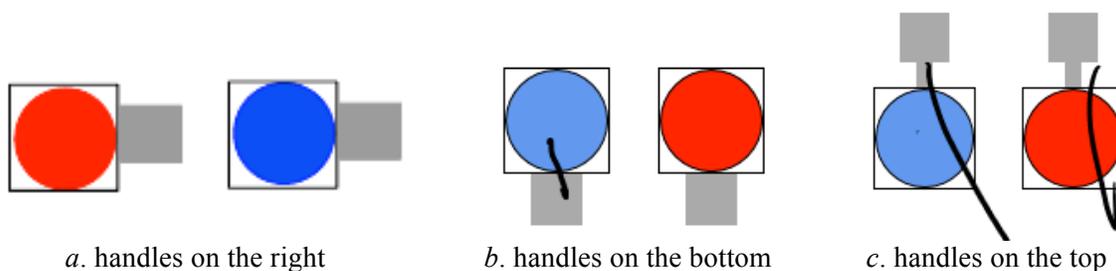


Figure 22. Tested stamp designs: Stamps are boxed in squares to differentiate them from their stamped images; the stamps have handles for pen interaction; extraneous marks indicate students accidentally drawing on the stamps instead moving the stamps

The stamps in Figure 22a caused difficulty for left-handed students, whose hands obscured the stamps when they placed the pen tip on the handles. Similarly, stamps with handles on the left side caused problems for right-handed students. Rather than specialize stamps for different handedness, we experimented with the stamps shown in Figure 22b, thinking that handles on the bottom would be less obscured by students' hands than handles on the top. Errant marks, such as shown in Figure 22b, indicated that students were having trouble placing the pen just on the handle and not on the stamp's image. Consequently, we experimented with the design in Figure 22c, adding a narrow neck in order to indicate that students should "grab" the larger area of the handle. Students still had problems with drawing instead of moving, as shown in the figure. Having handles on the top seemed more intuitive to students and did not cause the stamp to be obscured when moved.

Our final design, shown in Figure 4 and repeated below, has a large top handle that resembles a physical stamp handle. As shown in the student work throughout this document, students successfully used this design to create drawings containing multiple identical images.

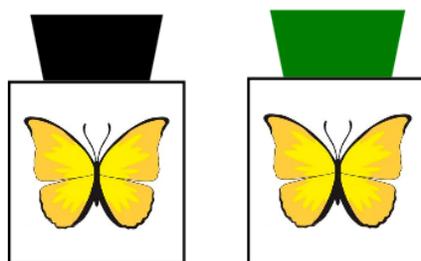


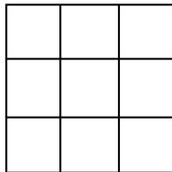
Figure 23. Stamp on left shows a stamp containing predefined image; stamp on right shows stamp appearance when pen is placed over the stamp handle; green handle indicates that stamp has been "grabbed" and can now be moved to create copies of stamp image

Interpreting Student Responses. One of the underlying questions of INK-12 research is: To what extent can a computer recognize and assess students' handwritten responses to relatively open-ended problems? This year we investigated an aspect of this problem—"parsing" the ink a student creates into structures that could subsequently be examined by algorithms that cluster student answers according to correctness or other teacher-specified characteristics. The thesis focused on testing the effects of structure on ink recognition in the classroom. We designed groups of consecutive problems on several math topics. Each of the questions in a group varied not in difficulty but in the amount of structure provided to the student.

For example, we created four different fraction problems, in which students had to color in a particular fraction of a shape, varying the amount of structure provided to the students in each exercise. The problem with the most structure was Problem 1 below; it included both the shape the student was to shade and grid lines for guidance. The expectation was that students would be more accurate in solving this

problem than those problems with less structure, and that the software would be more successful in distinguishing correct and incorrect answers in a problem with more structure.

Use the marker to color in $\frac{1}{3}$ of the shape below.



The second problem in the sequence was:

Use the marker to color in $\frac{1}{2}$ of this shape.



In the above problem, the shape is provided to the student, but there are no internal grid lines. Finally, in the problem below the student was asked to both draw the shape and color it.

Draw a square and color in $\frac{1}{4}$ of it.

We created a structure called a “Recognition Grid” to use as an interpretive tool, allowing us to test the hypothesis that the more structure there was in an exercise, the more accurate the interpretation results would be. This task required us to categorize student solutions by hand to compare to the judgments made by the Recognition Grid tool; because not all student responses were clearly correct or incorrect, we added a third category called “borderline” answers.

We tested several statistical methods for sorting students’ solutions into correct/incorrect/borderline categories. We found that for all the fraction coloring problems studied, regardless of the amount of structure in the problem, students’ answers were classified correctly with “correct” defined as exact answer $\pm 10\%$, “borderline” as exact answer $\pm 10\%$ to 20% , and “incorrect” as exact answer \pm more than 20% .

We also studied how well the Recognition Grids could interpret handwritten entries in tables, such as answers to the following problem:

Write the numbers 1 to 12 in order in the table, starting at the beginning of the top row.

We compared two different approaches to interpretation:

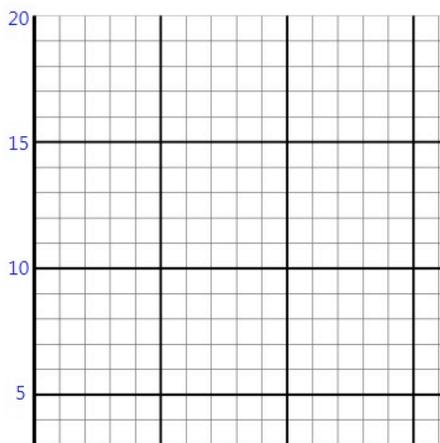
- 1) Cell by cell: The software interprets solutions cell by cell in the table. The problem with this method is that students’ answers may spill over into the neighboring cells and the errant ink strokes that are clipped may be mistakenly translated into numbers and letters.
- 2) All at once: The software takes all of the strokes in the table and interprets them at once. This method resolves the spillover problem, but it loses a key advantage of interpreting cell by cell, which is the ability to easily determine which cell contains which answers.

Our results demonstrated that cell by cell interpretation fared very poorly, correctly recognizing only about half of the students' entries. We conclude that further development should follow the "all at once" approach, which will require additional software support for mapping the numbers students entered to particular cells, or including a boundary around each cell so that fewer ink strokes are clipped.

Finally, we examined graphing problems such as the following. (We used color so that the software could easily validate the intended location of each point.)

Plot these points in the color indicated.

- (5, 10) black
- (0, 5) red
- (15, 15) green
- (2, 2) purple



We compared the Recognition Grid's performance on problems in which the background grid was visible to those in which it was not. Here we found the expected effect of structure: In the problem with a visible grid structure, the Recognition Grid's detection algorithms were more accurate when distinguishing between correct and incorrect solutions. When this structure was removed, accuracy dropped, and the Recognition Grid had to use a more relaxed interpretation scheme for judging correct solutions.

We are continuing to develop interpretation algorithms for other kinds of problems, e.g., those involving stamps or number lines, and to test the accuracy of built-in handwriting recognition software on fourth and fifth graders' text responses.

More technology findings are presented in the next two sections in which we discuss students' and teachers' reactions to using the technology.

5.3 Students' Reactions to Using INK-12 technology

We interviewed students informally in small groups or as an entire classroom to determine what they liked about using the tablets, what they didn't like and how they might improve the technology. The following comments are culled from both fourth and fifth grade classrooms.

Tablets as input devices. Students were consistently enthusiastic about the input affordances of the tablet. They enjoyed having multiple colors always available (without having to share scarce resources such as markers that ran dry as the year went on), found the multiple widths available for the pen useful, and appreciated the ability to erase anything they'd written. Interestingly, some of them were able to couch these affordances in terms of their effects on learning, e.g.:

- You can use multiple colors to differentiate between a part of an answer and the final answer.
- Erasing is much faster – and much less messy – on the tablet, so you are more likely to correct mistakes.
- You’re not limited in how much you can write because your marker won’t dry out.

Many students also said that the tablets made math and science more fun but couldn’t state any particular reason, and several thought they should use them for all subjects, not just math and science. We cannot discount novelty as a major influence on students’ attitudes, as we were only in any one classroom for a week. Longer classroom residencies in the next year will allow us to monitor how students react to the tablets over several weeks.

Several green-minded students commented that tablets are “good for the environment” because they provide students with copies of class materials without requiring lots of paper. Some teachers have mentioned these potential cost-savings associated with tablets – although it would take a while for the paper and copying savings to equal the cost of a tablet.

Suggestions for hardware and software improvement. Students had many suggestions for improving the tablet hardware and the INK-12 software. Some of their ideas reflected their depth of experience with technology, as they requested features they had used on other computers. Some of these were: buttons for Undo and Redo, more pen widths, a keyboard, waterproofing, an autosave option, a different interface for left-handed users, and an audio recorder to attach an oral explanation to written work.

A common source of frustration for students – as well as teachers and project staff – was the small size of the screen. It was often difficult to fit multiple objects on the same page, e.g. a table and a graph of the same data. We have some ideas of ways to deal with limited screen real estate – e.g. allowing a student to zoom in on individual objects or “lift” them off the page and move them around – but the size of the screen will always be a factor in usability.

One problem with the tablets was that the same features that made them fun to use – drawing tools, colors, erasers – made them distracting for some students, who would spend time drawing and erasing rather than working on a problem. Interestingly, students were sensitive to this issue and made suggestions for ways to minimize distraction. Among these: have colors available only when they are necessary for the particular assignment; disable the pen and/or tablet when the student has submitted the assignment.

Sharing student work and anonymity. Students in all classes expressed a variety of reasons why publicly sharing their work was useful. These included:

- You can learn from others’ mistakes.
- Other students can correct you, instead of just the teacher.
- You can see different/better ways to do a problem.
- Seeing other students’ work can motivate you to do better.

Students offered opinions both for and against keeping displayed student work anonymous. Many students thought student work should be anonymous so that someone who had the wrong answer wouldn’t feel bad and wouldn’t be teased. On the other hand, some students wanted to have their name on their work so that they could take credit for it – even if it were wrong. Some students wanted to know whose work they were looking at so that they would know who to ask for help on similar problems. In one discussion, students offered the idea that after students pressed the “send to teacher” button, they should be asked, “Do you want to share your work with the class?” and “Do you want to show your name?”

Communicating with the teacher. Although we didn't yet have the ability for students to communicate privately with the teacher—or for the teacher to send messages to individual students – students imagined a variety of ways they might use such a feature. The most common suggestion was using an individual channel to the teacher as a way of asking for help privately and avoiding the embarrassment that might accompany raising a hand. Students imagined they could push a button on their tablet and a notification could pop up on the teacher tablet. In this way, the teacher could keep track of the order in which students asked for help which, students imagined, would prevent fights.

Some students expanded on this idea by suggesting the equivalent of instant messaging with the teacher (not an idea the teacher was enthusiastic about). Teachers and students agreed, however, that it would be great if teachers could write on students' work and send it back to them. In fact, these are capabilities we are planning to add to the system this coming year.

5.4 Teachers' Reactions to Using INK-12 technology

The INK-12 evaluator, David Reider, interviewed each classroom teacher after she used the tablets. The following remarks are grouped into several common topics of conversation.

Teacher Interface. Teachers were pleased with the new software interface and functions, much of which was based on their feedback and suggestions during the exploratory project. One teacher particularly liked the multiple display windows (thumbnails) viewable on the teacher's tablet.

“For me, the multiple display is much more efficient, well-liked and appreciated. Four [student screens at once] I thought was ideal. I also chose people who aren't normally with me. I chose some of my intensive-based lesson kids because I thought that they would do their work. They did have some good ideas.”

One teacher anticipated her use of a function not ready at the time, the ability to sort student work.

“I think the different options that we had talked about... sorting of the work and being able to mark it correct or incorrect, I would like to see these functions... will be great when working properly.”

Teachers also commented on how the tablet improved their ability to review student work and how it would help them teach.

“The afternoon I was able to look through their work and be able to look through some of the work they had done. I took the tablet with me and prepared for the next day. I took it home, I sat in bed and I went through all the slides. Yes, I did because it's interesting. It was more efficient for me to do it with the tablet, to be able for me to just quickly see...and make a display of what I wanted to show.”

Inscriptions. There was consensus that inscriptions allow the students to draw and express thoughts pictorially as well as with text, opening up the description process more than keyboarding typically allows,

“... well writing [using stylus/pencil] is easier because keyboarding it's not taught here so they don't type fast so unless they use it as home they can be really slow, whereas writing is a little more quicker”

“It shows their thinking and processes; that's the most important thing for me as a teacher, that's the biggest thing. Some kids on the tablet I couldn't believe how much writing they got in the boxes because that was one of those things that will you be able to fit everything on it?”

Further, text alongside drawings helped the teacher quickly assess the quality of the work,

“ I did [see a lot of written draft work] and I saw a lot of people that actually had the wrong number sentence, like had one right number sentence and then had a wrong number sentence so that I knew that they really didn't get it. They were putting number sentences that equaled the

total amount but it wasn't representing the fractional parts that they had placed out. You would not see this if they typed, because the drawings wouldn't be there alongside."

One teacher commented on how students liked the flexibility of the interface, but also noted that the computer screen had size and space limitations,

"Students are able to change it, make it [drawings] different colors. It's great, but there are limits to the screen... I think the limits were hard for them. Some kids were like "Why can't I write outside the box?" They were a little annoyed that they didn't have space for their figuring. They didn't like that they couldn't write outside of it."

Displaying Student Work for Discussion. In one school where we worked, every classroom received a SMART Board during the past several years. One teacher made the distinction between what she could do with the SMART Board and what she wanted as functionality from the INK-12 system.

"Since I first started [INK-12] four years ago, I've gotten the SMART board and so I've changed the way that I teach in the sense that I do a lot of things on the board and when I plan my lessons, I make [them] similar to the tablet slides... that's why I feel like the thing I was really interested to see was that feedback portion and sending up the kids."

Another teacher in the same school concurred:

"The bonus of the tablets was when they had their chart sheets and they sent them to me and I was able to put their work up, the difference is even with a SMART board I'm still not able to take their individual work and put it on the board very easily and very quickly, very easily. I don't just show them each other's work sheets."

These remarks support our project's emphasis on tools for displaying and discussing student work in two ways. First, other technologies that are being widely disseminated in classrooms – while they may be pedagogically useful – do not facilitate conversations about student work. Second, teachers who have even limited experience displaying student work saw the benefits for students, as the following quote indicates.

"So they never really see each other's work and it was very interesting when they saw each other's work on a work sheet; the comments that they made about other people's work like oh that's really neat or they could see like- there was a little bit of almost competition between a kid like well I wanted mine to be like long enough or better because they saw other quality work so for some of those kids that just rush through a worksheet and don't put a lot of effort in I thought well what a bonus..."

Motivation and Engagement. It was no surprise that students were engaged with the tablets when we first introduced them, as they were a new addition to the classroom. However, teachers felt students' interest went beyond the novelty effect.

"We're always looking for more things that are keeping kids engaged during the conversation and the tablet has that effect. You can scroll through different screens, you know, being able to send and project something as opposed to holding a whiteboard."

"I think that its keeping more kids engaged and holding more kids accountable for being invested in their work because it's projected in front of others and because they know that at any point, can you repeat what that person said in other words and so, it's just a more engaged way of interacting with them, that tablets support."

Teachers felt that the motivation and engagement that resulted from using tablets was related to how students perceived learning and their participation in school, and that seeing what others did encouraged students to raise their own standards.

“Kids ... like seeing whatever other people do and that makes that a lot easier. So in that respect they definitely understand things better but I really think there's also something to be said about that motivation and trying to be the best you can but seeing what other people's best is and setting the bar a little bit higher because there is a real tendency for kids to kind of just do the bare minimum, especially around fifth grade like this is good enough and sort of have kids push that bar.”

Classroom Management. Teachers differed in how well they felt they could integrate the tablet into their classroom management style. Some felt it was difficult to walk around, look at student work, respond to students immediately, and lead a lesson all at once.

“When it does work and it's a function of your everyday use in the classroom and you're used to it and the kids send it and you can go through it quickly, because I feel like there was a lot of times where I was pulled away from the kids because I was trying to look at their work on the thing. And it wasn't working, so I felt like I was kind of wanting to put the tablet down and just go walk around and look at the kids because I felt like I didn't want to lose class instructional time”

While others recognized the potential,

“... being able to send your teacher a message or I need help or things like that and not having to raise your hand. That opens up a lot of really great possibilities, I think.”

and felt able to process multiple tasks at once, including responding to student submissions “on the fly,”

“Yes I was able to look at [real time incoming thumbnail] submissions from students, and process it while leading the class, definitely because while they're working they're coming in at different times and there definitely was enough time to look through and quickly pick a few. It was really easy to make- I like the multiple displays you can make now.”

6. Evaluation

As detailed in the Evaluation Report, submitted separately, the evaluator's data collection included:

- formal observation of trials using an observation protocol
- post-trial interview with participating teachers
- inventory analysis of student work samples
- student comments collected during and at end of trials

Observations were coded and analyzed to discern patterns of change among identified learning dimensions present during the trials. Teacher interviews were coded and emergent themes noted and analyzed. Student comments were reviewed and repeated themes noted and analyzed.

Excerpts from the Evaluation Report:

p. 4. These instructional dimensions are included in the analyses and abbreviated in the chart below:

L lecture/presentation	IN use of INK technologies
CL cooperative learning (roles)	SND sending tablet data to teacher or student
HOA hands-on activity/materials	RT teacher using real-time student data in lesson
I interruption	SGD small group discussion (pairs count)
SP student presentation (formal)	TIS teacher interacting w/student
LWD lecture with discussion	D demonstration
GT general technology	CG (computer group)
CD class discussion	WW writing work (paper/pencil)
A assessment	REV student revision of submitted work
RSW reading seat work	ACT active learning
PAS passive learning	

The following chart presents the relative frequency of dimensions observed from all the classrooms attended, providing a composite picture of the instructional practices engaged while using INK-12 tablets. Evidence is recorded as percentage of class time evident, dimensions may occur concurrently.

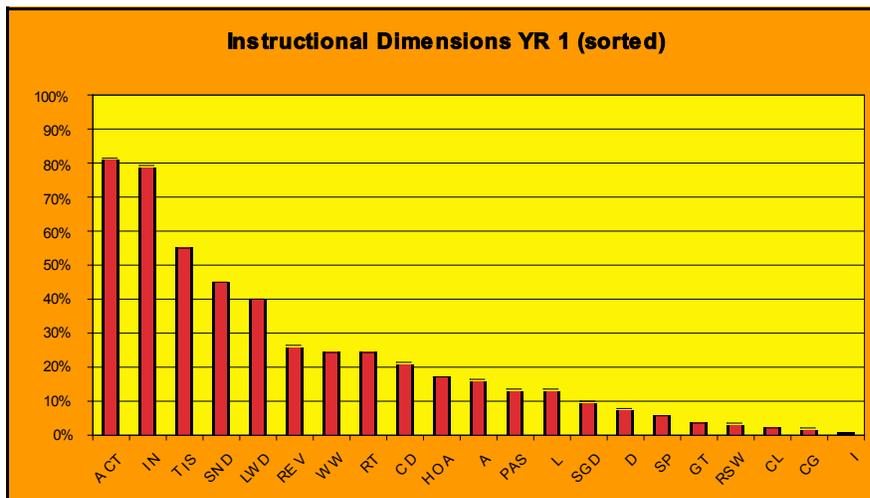


Figure 1: Instructional dimensions present, all classrooms YR 1, sorted

Note that the highest rated (most frequent) dimension was evidence of active learning (81%), followed by INK-12 tablet technology use (79% of the time). The next highest categories include teacher interacting with student and students sending INK-12 data/assignments to teacher. The lowest categories include Interruption, computer group use (tablets were provided in one-to-one ratios), cooperative learning, and reading seat-work. What this suggests is that students were quite engaged during the residency (high active learning), even after three or four class periods; that INK-12 activities were taking place a lot of the time, and that submissions occurred frequently. Notice that revisions of work (and re-submitting) occurred around 26% of the time, demonstrating that the tablets encourage revision, adopting changes discussed during the presentation periods.

Direct lecturing, interruptions, reading seat-work, and general technology all rate very low; the INK-12 lessons involve very interactive classroom work. Students showed a very high engagement at nearly 90% of the time highly engaged, 10% of the time engaged at a medium level, none at low engagement. Certainly much might be attributed to the novelty factor and the fact that students found the tablets simply fun to use, but the engagement led directly to increased motivation.

p. 13. Classroom use of INK-12 technology was perceived as very successful by teachers and students. The first implementations have yielded many positive and constructive ideas, and have validated both the technical design of the interface and the presentation of the curriculum. We find it particularly interesting to witness an increase in perceived student engagement and motivation, and evidence of higher cognitive activities most often associated with inquiry-based learning and facilitated by group learning through conversation and shared presentations.

p. 14. The implementations went very smoothly overall; there was ample technical setup and maintenance support throughout; when problems occurred, they were addressed immediately. A local classroom INK-12 LAN with dedicated server insured that wireless communication would not be hindered by or subject to the common difficulties found when using school networks (bandwidth and security obstacles). While this model may not be the best when choosing to scale, it insures that the prototypes will operate in a controlled environment, enabling the researchers to collect their data.

See the Year 1 Evaluation Report for more details.